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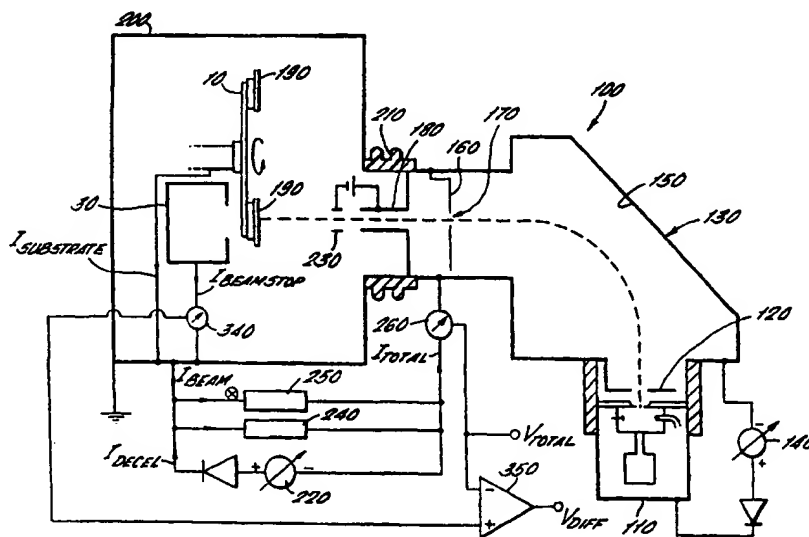
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(54) Title: ION IMPLANTATION BEAM MONITOR



## (57) Abstract

An ion implanter, the total return current between the substrate holder and flight tube is measured. Measuring the total current returned to the flight tube provides a useful indication of the total ion current in the ion beam leaving the flight tube as well as any electrons travelling back to, and being absorbed by, the flight tube. This in turn permits the quality of the ion beam post mass selection to be monitored, continuously if desired. The total current returned to the flight tube can be compared with the current measured by the beam, the latter varying rapidly with time as the beam stop is periodically occluded by the rotating substrate wheel. In order to generate a potential difference between the substrate holder and the flight tube, either a power supply or an active resistance such as an FET chain can be employed.

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ION IMPLANTATION BEAM MONITOR

5 This invention relates to an ion implantation  
beam monitor, in particular for monitoring the quality  
or stability of an ion beam in an ion implanter which  
implants ions into substrates such as semiconductor  
wafers.

10 Semiconductor devices are typically formed from a  
semiconductor substrate material into which atoms or  
molecules of selected dopants have been implanted or  
defused. The dopant particles produce regions in the  
semiconductor substrate having varying conductivity.  
By selecting appropriate dopant materials, the  
15 majority charge carrier may be locally altered within  
the substrate.

One preferred technique for adding dopant  
materials to semiconductor substrates uses ion  
implantation. This technique minimises the size of the  
20 device features created by the dopants within the  
substrate, reducing the overall size of the  
semiconductor device itself and increasing operational  
speed.

The principles of operation of an ion  
25 implantation apparatus will be familiar to those  
skilled in the art. Briefly, a plasma generates  
positive ions of the selective dopant material in an  
ion source. The required positively charged ions are  
extracted from the ion source, which are accelerated  
30 by application of an acceleration potential through a  
magnetic field. The magnetic field is generated by a  
mass selection arrangement which bends the extracted  
ions around a curved path. The radius of curvature of  
the flight path of the ions is dependent upon the  
35 mass/charge ratio of the individual ions. The exit of

the mass selection arrangement has a slit within it so that only ions having a predetermined mass/charge ratio can exit the mass selection arrangement.

Those ions exiting the mass selection arrangement  
5 impinge upon a semiconductor substrate to be doped. Typically, this substrate will have previously been patterned with photo resist so that only selected regions are doped.

The depth to which ions are implanted in the  
10 substrate will depend upon their energy when incident upon the substrate. In order to generate ions for implantation, it is standard practice to provide an arrangement to generate a desired potential difference between the "flight tube" and sample holder. The  
15 flight tube is an expression used throughout this specification and the claims to refer to the metalwork of the mass selection arrangement which is normally all at a common potential with reference to earth. However, the term "flight tube" is also applicable to  
20 any structure where corresponding electrode arrangements arise - for example a structure which itself has a potential referenced to earth and from which the potential of the ion source is in turn referenced. For example, the flight tube may contain  
25 an r.f. accelerator or booster positioned downstream of the mass selector for which the final exit electrode of the booster is at a potential referenced to the mass selection.

Usually, the target substrate is held at or near  
30 earth potential. If the flight tube is at a positive potential with respect to the sample holder/target substrate, then the ions are accelerated post mass selection. This is called "post acceleration", and is desirable when deep implantation of ions is required.  
35 On the other hand, if the flight tube is at a negative

potential with respect to the sample holder, then the ions are decelerated post mass selection. This is called "post deceleration". Post deceleration is typically employed to produce very shallow structures within the surface of the substrate, to decrease the size and increase the speed of the resultant semiconductor device.

In some arrangements, it is desirable to operate the flight tube at substantially the same potential as the substrate holder, so that there is no post acceleration or deceleration. This mode of operation is termed the "drift mode".

Frequently, the cross-sectional area of the ion beam at the substrate is less than that of the substrate, in order to prevent ions in the beam from sputtering the walls of the apparatus and introducing impurities, and to increase doping uniformity. This necessitates scanning of either the substrate relative to a fixed direction ion beam or scanning the ion beam across a fixed substrate. In practice, it is preferable to scan the substrate while maintaining the ion beam in a fixed direction.

It is important when doping substrates with an ion beam from an ion implantation apparatus that the ion current striking the substrate be monitored. This is to ensure correct doping. If, for example, the ion beam contains a drop-out, then the substrate will not be doped properly. Several ways of monitoring the beam have been proposed, and a Faraday detector, such as a Faraday cup or bucket, is often employed.

In one known apparatus, the Faraday detector acts as a beam stop arranged down stream of a rotating spoked wheel. The rotating wheel carries a plurality of substrates to be doped and is scanned across an ion beam. The beam stop collects ions passing through or

missing the wheel, as well as any secondary electrons generated. In another apparatus, a solid wheel is employed instead, and the Faraday detector is arranged upstream of the wheel.

5 Each of these ion beam monitors suffer from drawbacks, however. It is therefore an object of the present invention to provide an improved apparatus and method for monitoring the ion beam.

10 According to a first aspect of the present invention, there is provided an ion implantation apparatus comprising a holder for a substrate to be implanted, a source of ions to be implanted in the substrate, a flight tube through which ions from the source travel towards the holder, an ion accelerator  
15 arranged to supply an acceleration bias between the source and the flight tube such that the ions are accelerated to an acceleration energy, a power supply arranged to generate a desired potential difference between the substrate holder and flight tube, an  
20 electrically conductive return current path connected to conduct the entirety of the current returned to the flight tube such that the flight tube is maintained at a desired potential relative to the substrate holder, and a return current monitor arranged to provide a  
25 signal representative of the return current flowing through the return current path.

Measuring the total current returned to the flight tube provides a useful indication of the total ion current in the beam leaving the flight tube, as  
30 well as any electrons travelling back to, and being absorbed by, the flight tube. This in turn permits the quality of the ion beam post mass selection to be monitored, continuously if desired. Previously, for example when using a beam stop behind the substrate  
35 holder, the ion beam could only be monitored (via the beam stop current) when the ion beam was not absorbed by the substrate holder. This prevented drop-outs in

the ion beam, for example due to arcing in the ion source, from being detected if these occurred whilst the substrates were absorbing the ion beam rather than the beam stop.

5            Preferably, the power supply generates a potential difference between the substrate holder and flight tube such that the ions are decelerated between the flight tube and the substrate holder. Although post mass selection acceleration is desirable in  
10        certain cases, it is more often preferable to decelerate the ions prior to impact with a substrate.

          According to a second aspect of the present invention, there is provided an ion implantation apparatus comprising a holder for a substrate to be  
15        implanted, a source of ions to be implanted in the substrate, a flight tube through which ions from the source travel towards the holder, an ion accelerator arranged to supply an acceleration bias between the source and the flight tube such that the ions are  
20        accelerated to an acceleration energy, a low resistance, electrically conductive return current path connected to conduct the entirety of the current returned to the flight tube such that the flight tube is maintained at substantially the same potential as  
25        the substrate holder, and a return current monitor arranged to provide a signal representative of the return current flowing through the return current path.

          Connecting the flight tube to the substrate  
30        holder via a low resistance path means that the ions exiting the flight tube are neither accelerated nor decelerated as they approach the substrate holder.

          Preferably, the ion implantation apparatus of the first and second aspects of the present invention  
35        further comprises a beam stop arranged to absorb a portion of the ion beam not absorbed by the substrate or substrate holder, and to generate a beam stop

current therefrom, the beam stop current being returned to the flight tube via the return current path. In that case, the apparatus may further comprise a comparator arranged to provide a signal  
5 representative of the difference between the return current through the return current path and the beam stop current. Thus, the beam stop current may be compared, in real time, with the total current being returned from the substrate, substrate holder and beam  
10 stop to the flight tube.

According to a third aspect of the present invention, there is provided an ion implantation apparatus comprising a holder for a substrate to be implanted, a source of ions to be implanted in the  
15 substrate, a flight tube through which ions from the source travel towards the holder, an ion accelerator arranged to supply an acceleration bias between the source and the flight tube such that the ions are accelerated to an acceleration energy, a beam stop  
20 arranged to absorb a portion of the ion beam not absorbed by the substrate or substrate holder, and to generate a beam stop current therefrom, an electrically conductive controlled current path connected to conduct the entirety of the current to  
25 the flight tube such that a desired potential difference is maintained between the substrate holder and flight tube, and a comparator arranged to provide a signal representative of the difference between the controlled current through the return current path and  
30 the beam stop current.

Comparing the beam stop current with the total current returned to the flight tube allows a cross check on beam stop accuracy to be made, when the ion beam does not impinge upon any part of the substrate  
35 holder.

The apparatus may also include scanning means for scanning the ions relative to the substrate, and



optionally relative to the beam stop as well. For example, the substrate may be scanned relative to a fixed ion beam direction.

5 Preferably, the substrate holder comprises a plurality of substrate supports each mounted relative to a rotatable hub. The beam stop may include a Faraday-type detector.

10 The invention also extends to a method of implanting ions in a substrate at a desired implant energy, comprising accelerating ions to a transport energy by supplying an acceleration bias between an ion source and a flight tube through which the ions travel, transporting the ions through the flight tube to the substrate, generating a return current signal  
15 representative of the entirety of the current returned to the flight tube, the return current being controlled such that a desired potential difference is maintained between the substrate holder and flight tube, and monitoring the ions transported through the  
20 flight tube to the substrate based upon the signal representative of the return current.

Furthermore, there is provided a method of monitoring the quality of an ion beam in an ion implantation apparatus, comprising accelerating ions  
25 to a transport energy by supplying an acceleration bias between an ion source and a flight tube through which the ions travel, transporting the ions as in an ion beam through the flight tube to a substrate, generating a return current signal representative of  
30 the entirety of the current returned to the flight tube, the return current being controlled such that a desired potential difference is maintained between the substrate holder and flight tube, and monitoring the quality of the ion beam based upon the signal  
35 representative of the return current.

The invention may be put into practice in a number of ways, one of which will be described by way of example only and with reference to the accompanying drawings in which:

5        Figures 1a and 1b show front views of a substrate holder and beam stop;

      Figure 2 shows the output of the beam stop of Figure 1 as a function of time;

10       Figure 3 shows a schematic view of an ion implantation apparatus according to a first preferred embodiment of the present invention including a first return current monitor;

      Figure 4 shows, schematically, the current paths in the ion implantation apparatus of Figure 3;

15       Figure 5 shows the output of the beam stop of Figure 1 together with the output of the further beam current detector of Figure 3; and

20       Figure 6 shows an ion implantation apparatus according to a second preferred embodiment of the present invention including a second return current monitor.

      Figures 1a and 1b show a typical substrate holder 10 looking along the lines of ions exiting the slit in the mass selection arrangement. The substrate holder 25 10 is of the spoked wheel type and comprises a plurality of substrate supports 20, onto which substrates to be doped may be affixed. The substrate supports 20 are spaced equidistantly from a central hub 22 by a plurality of spokes 24. The central hub 30 22 is connected to a drive 26 by a shaft 28. The drive 26, which may for example be an electric motor, drives the shaft 28 such that the hub 22 is caused to move reciprocally in the manner of an inverted pendulum. Referring to Figure 1a, this motion is 35 indicated by the arrows AA'. In the following description, one movement of the shaft from its leftmost extension at A', to its rightmost extension

A, and back to its leftmost extension A', is termed a substrate scan.

In addition to its reciprocal motion, the hub is also rotated about its axis, as indicated by the second arrow B in Figure 1a. Thus, the ion beam, which normally follows a fixed, linear trajectory once it exits the mass selection apparatus, is caused to scan across the plurality of substrates held on the substrate supports 20 by the reciprocating and rotating movement of the substrate holder 10.

In this preferred embodiment, the ion beam is aimed at a beam stop 30 arranged downstream of the substrate holder 10, as shown in Figures 1a and 1b. The beam stop 30 includes a Faraday type current detector 40, connected to ancillary circuitry 50 which generates a beam stop current representative of the charge built up in the Faraday type current detector 40.

When the shaft 28 of the substrate holder is at its furthest point of travel away from the beam stop 30, as shown in Figure 1a, the ion beam, which is directed at the Faraday type current detector 40, strikes only the current detector itself, and completely misses the rotating substrate support 20. The beam stop current is at this point similar to the actual ion beam current. However, as the shaft 28 of the substrate holder 20 moves back towards the beam stop 30, the current detector 40 becomes obscured by the plurality of rotating substrate supports as they pass in front of it. The apparent current measured by the beam stop thus reduces as the ion beam is absorbed instead by the substrates upon the substrate supports 20.

It will be understood that other substrate holder arrangements are contemplated. For example, a solid wheel (rather than a spoked wheel) may be used. Furthermore, the substrate holder may move

reciprocally up and down (or side to side) in a straight line rather than in an arc as described above.

It will be understood that other substrate holder arrangements could be used.

Figure 2 shows a schematic plot of beam stop current  $I_{\text{beam}}$  against time. Over the period marked P in Figure 2, the beam current is a maximum, and occurs when the shaft 28 of the substrate holder 10 is at its furthest point A' away from the beam stop 30. As the shaft 28 moves back towards the beam stop 30, the substrate supports 20 partially block the passage of the ion beam to the current detector 40. At this point, the ion beam is able to pass wholly through the gaps between the substrates, however, and the beam current thus becomes a series of negative pulses between  $I_{\text{beam}} = I_{\text{max}}$  and  $I_{\text{beam}} < I_{\text{max}}$ , as shown in region Q of Figure 2.

The shaft 28 continues to move towards the beam stop 30, and the minimum current in the current pulses reduces to zero as the ion beam is wholly absorbed by the substrates as they pass. Furthermore, the maximum current in each pulse reduces, as the height of the ion beam is greater than the spacing between substrates and a part of the ion beam is captured by the substrates at all times. This is shown in region R of Figure 2.

As the substrate supports 20 pass to the left of the current detector 40 (when viewed along the line of the ion beam in the arrangement of Figures 1a and 1b) the measured current increases again. A subsidiary maximum is reached when the ion beam is partially obscured only by the spokes 24 of the substrate holder 10. This is shown at S in Figure 2.

The shaft 28 then starts to return back towards its point of furthest travel (A') from the beam stop 30 and the current eventually reaches a primary

maximum again, at T, as shown in Figure 2. It will be appreciated that, in fact, the widths of the pulses (several milliseconds each) are several orders of magnitude less than the time for one scan cycle, and in practice only the carrier wave (indicated by a broken line in Figure 2) is detected, rather than the modulated output of Figure 2. This is because the current to voltage converter, explained below, includes a low pass filter in series with its output, that rolls off at 80 Hz. This filters out the pulses shown in Figure 2, which typically have a frequency between 350 Hz and 550 Hz.

The use of a beam stop in the arrangement of Figure 1 thus prevents accurate measurement of ion beam current, and hence meaningful ion beam stability monitoring, over most of the substrate doping operation.

Referring now to Figure 3, an ion implantation apparatus 100 is shown. The apparatus comprises an ion beam source 110, such as a Freeman or Bernas source, which is supplied with ions of a substance which is to be implanted into a substrate. The ions are extracted from the ion source 110 by an extraction electrode assembly 120 which is in electrical contact with a flight tube 130. The flight tube 130 is electrically isolated from the ion source 110 and a high tension power supply 140 applies a potential difference between the flight tube 130 and ion source 110.

This potential difference causes positively charged ions to be ejected from the ion source 110 into the flight tube 130. The flight tube 130 includes a mass analysis arrangement comprising a mass analysing magnet 150 and a mass selection electrode 160. Upon entering the mass analysis apparatus within the flight tube 130, the electrically charged ions are deflected by the magnetic field of the mass analysis magnet 150. The radius of curvature of each ion's

flight path is defined, for a constant magnetic field, by the mass/charge ratio of the individual ions.

5 A mass selection slit 170 is provided within the mass selection electrode 160, so that only ions having a chosen mass/charge ratio can exit the mass analysing apparatus. Those ions passing through the slit 170 enter a tube 180 which is electrically connected to, and integral with, the flight tube 130.

10 The mass selected ions exit the tube 180 and strike a semiconductor substrate 190, mounted upon a substrate holder 10. The substrate holder 10 holds a plurality of substrates, as has been described in relation to Figures 1a and 1b. Located behind (i.e, downstream of) the substrate holder 10 is a beam stop 15 30.

To maintain the beam current at an acceptable level, a minimum ion extraction energy of about 10keV is employed. The ions are maintained at this energy throughout the flight tube until they emerge from the tube 180 downstream of the slit 170. It is often 20 desirable for the energy at which the ions impact the substrate 190 to be considerably lower than the 10keV extraction energy. For example, the energy at impact on the substrate may desirably be as low as several 25 hundred electron volts. Thus, a reverse bias voltage must be applied between the substrate 190 and the flight tube 130. The flight tube is, of course, at a negative potential relative to the ion source 110 by virtue of the regulated high tension power supply 140.

30 The substrate holder 10 and beam stop 30 are contained within a housing 200 which is mounted relative to the flight tube 130 by insulating standoffs 210. Both the beam stop 30 and substrate holder 10 are connected to the flight tube 130 via a 35 deceleration power supply. Normally, the beam stop and substrate holder are held at a common ground potential so that, in order to decelerate the

positively charged ions, the deceleration power supply 220 generates a negative potential with respect to the grounded substrate holder beam stop at the flight tube 130.

5        In order for the deceleration power supply 220 to maintain a regulated voltage between the substrate holder/beam stop and flight tube, it is important to ensure that a forward current flows through the deceleration power supply 220. This is achieved by  
10       connecting a deceleration supply load resistance 240 in parallel with the power supply 220.

         In order to provide cooling to assemblies in the beamline and ion source areas of the implanter, a closed circuit cooling water flow is required from a  
15       heat exchanger located at ground potential. The flow and return pipes must cross the post mass acceleration or deceleration voltage gaps. The wafer is slightly electrically conductive and part of the return current flow from the substrate passes through these pipes.  
20       This is a further effective load resistance in parallel with the deceleration supply 220. Although the current returned through the cooling pipes is typically negligible, the current through the water used to cool the substrate holder (which is usually deionized) will not necessarily be negligible. For  
25       example, when high post mass acceleration or deceleration voltages are employed, a cooling water current of several mA may arise. To take this into account Figure 3 shows a cooling system resistance  
30       250, in parallel with the deceleration supply load resistance 240 and the deceleration power supply 220.

         The current flowing through the deceleration supply load resistance 240 will then be the sum of the forward current through the deceleration power supply  
35       220 ( $I_{\text{decel}}$ ) and the net beam current  $I_{\text{beam}}$  absorbed by both the substrate 190 and beam stop 130 minus a small cooling system water current.

The output of the beam stop 30 is monitored by a first current monitor 340, which generates a voltage signal representative of the beam stop current. This voltage signal is connected to one input of a comparator 350, as will be described in more detail below.

The ion implantation apparatus 100 also contains a second current monitor 260 arranged in the path of the total current (the sum of the beam and deceleration currents) as it returns to the flight tube 130. This second current monitor 260 also generates a voltage signal  $V_{TOTAL}$ , which indicates the total current returning to the flight tube. In one embodiment, the signal  $V_{TOTAL}$  may be measured directly without comparing it to the beam stop current.

Alternatively, the signal  $V_{TOTAL}$  is fed to a second input of the comparator 350. Thus, the comparator 350 generates an output  $V_{DIFF}$  representative of the difference between the beam stop current  $I_{beam\ stop}$  and the total current  $I_{TOTAL}$  returned to the flight tube 130.

Referring now to Figure 4, a schematic diagram of the current flow and the two current monitors is shown. Features common to Figures 3 and 4 are labelled with similar numerals.

The incident ion beam 300 impinges upon the substrate holder 10 and beam stop 30. It will be appreciated that, whilst in Figure 4 the beam is shown scanned relative to a stationary wheel and beam stop, it is in practice preferable to scan the wheel whilst maintaining the ion beam 300 stationary and directed towards the beam stop.

The output of the beam stop 30 is connected to ground potential via a first current monitor shown generally at 340. The first current monitor 340 includes a current-to-voltage converter employing a first operational amplifier 360. The output of the



beam stop 30 is fed to the inverting input of the operational amplifier 360, the non-inverting input thereof being grounded. In parallel with the first operational amplifier 360 is a first feedback resistor 370. As the non-inverting input of the first operational amplifier 360 is at ground potential, the inverting input is at a virtual earth potential. The inputs of an operational amplifier do not draw a current, and the first current monitor 340 therefore acts as a current-to-voltage converter. The current flows through the operational amplifier from ground via power rails 362, 364.

The output of the beam stop current to voltage converter is filtered by a low pass filter (not shown) to remove the relatively high frequency pulses caused by the preferred "wheel" shape of the substrate holder as it cuts the ion beam. Active or passive devices can be used to filter the signal and suitable ways of doing this will be apparent to the skilled person.

The voltage output of the first current monitor is connected to a differential amplifier 350, as previously described in connection with Figure 3.

The total current from the substrate holder 10 and beam stop 30 passes through the parallel arrangement of the deceleration power supply 220, the deceleration supply load resistance 240, and any cooling system resistance 250. The total current  $I_{TOTAL}$  is fed to a current termination plate 310 which in turn is attached to a second current monitor 260 which operates in a similar manner to the first current monitor 340. In particular, the second current monitor includes a second operational amplifier 320, having its inverting input connected to the current termination plate 310. The second current monitor 260 also has a second feedback resistor 330 arranged in parallel with the second operational amplifier 320. Again, current flow through the second operational

amplifier 320 is maintained through a DC supply (not shown) attached to the power rails of the second operational amplifier 332,334.

5 The advantages of monitoring the total current returning to the flight tube, instead of, or as well as, the current from the beam stop 30, may be seen from Figure 5a, which shows the measured beam current as a function of time. The curve labelled  $I_{\text{beam stop}}$  is the current measured only by the first current monitor 10 340 (indicative of the current from the beam stop). The curve marked  $I_{\text{TOTAL}}$  is the total current returned from the beam stop 30 and substrate holder 10 to the flight tube. In other words, the curve marked  $I_{\text{TOTAL}}$  should be broadly indicative of the ion beam current 15 at the point when it impacts the substrate holder/beam stop assembly. Any arcing, for example, in the ion source will manifest itself as a drop-out in the ion beam. This in turn may be monitored by monitoring  $I_{\text{TOTAL}}$ . At any time during the implantation cycle, a 20 qualitative indication of ion beam integrity may then be obtained. In particular, the voltage signal which is an output of the current monitor 260 allows wide band stability monitoring of the ion beam.

Furthermore, the problem of ripples in the 25 current measured by the beam stop is largely avoided with the apparatus of the present invention.  $I_{\text{TOTAL}}$  is slightly distorted due to back streaming electrons generated when the ion beam is striking the substrates. For positively charged ions, any electrons 30 liberated from the substrates are accelerated away from the substrates (for ion deceleration), thus adding to the current returned to the flight tube 130. The beam stop effectively traps secondary electrons, however, and there are no back streaming electrons to 35 augment the current when the substrate holder does not occlude the beam.

Figure 5b shows the output of the differential

amplifier 350. When the ion beam is entirely incident upon the beam stop 30, the beam stop current substantially equals the current being returned to the flight tube, i.e.  $I_{\text{BEAM STOP}} = I_{\text{TOTAL}}$ . Thus, the  
5 differential output of the amplifier 350 is approximately zero.

As the beam begins to impinge upon the substrates 190, the beam stop current reduces, as explained in relation to Figure 2. The total current returned to  
10 the flight tube does, however, not reduce by the same amount, and the output of the differential amplifier 350 rises.

When the beam moves off the substrates 190, and the beam stop is only partially obscured by the  
15 substrate holder spokes 24, the beam stop current rises again and the output of the differential amplifier 350 reaches a subsidiary minimum. The output of the differential amplifier 350 reaches another maximum as the beam passes back over the  
20 substrates 190 and the beam stop current drops towards zero once more. Finally, as the ion beam coincides with the beam stop once more, the output of the differential amplifier drops to approximately zero.

An alternative embodiment of the present  
25 invention is shown with reference to Figure 6. Once again, parts of the apparatus common to Figures 3, 4 and 6 are labelled with similar reference numerals.

As shown in Figure 6, rather than employing a deceleration power supply, a variable resistance 400  
30 is placed in the current path which returns the ion beam current from the substrate holder 10 and beam stop 30 back to the flight tube 130. Although the variable resistance 400 may consist of passive devices, it is preferable to use a series of active  
35 devices, such as field effect transistors (FET's). The manner of operation of the device of Figure 6 is described in more detail in GB 9523982.8. Briefly,

the potential difference between the substrate holder/beam stop (normally held at ground potential) and the flight tube 130 is controlled by varying the resistance of a chain of FET's connected in series  
5 between the substrate holder/beam stop (at ground potential) and the flight tube. This is done by measuring the voltage across the FET chain with a potential divider, buffering it and comparing it with a reference voltage  $V_{ref}$  in a differential amplifier.  
10 The error signal (i.e, the amplified difference between the desired deceleration potential and the actual deceleration potential as measured by the potential divider) adjusts the effective resistance of the FET chain.

15 The potential drop across the FET chain,  $V_{TOTAL}$ , is indicative of the total current returned to the flight tube 130. In one embodiment, this is fed to a comparator, such as a differential amplifier 350 (see Figure 6). The other input to the differential  
20 amplifier 350 is a voltage representative of the beam stop current. This is derived from a beam stop current monitor 340. The output of the differential amplifier 350 is similar to that shown in Figure 5b.

As with the apparatus shown in Figure 3, the  
25 voltage signal  $V_{TOTAL}$  may be measured directly, rather than being compared with the beam stop current signal.

Although a differential amplifier has been described in connection with Figures 3 and 6, it will be understood that a software comparison may be more  
30 suitable in some circumstances. In the case of post mass selection acceleration or deceleration (as opposed to the "drift mode"),  $V_{TOTAL}$  and  $V_{BEAMSTOP}$  may be separated by kilovolts and here, a software comparison would be preferred.

CLAIMS:

1. An ion implantation apparatus comprising a holder for a substrate to be implanted, a source of  
5 ions to be implanted in the substrate, a flight tube through which ions from the source travel towards the holder, an ion accelerator arranged to supply an acceleration bias between the source and the flight tube such that the ions are accelerated to an  
10 acceleration energy, a power supply arranged to generate a desired potential difference between the substrate holder and flight tube, an electrically conductive return current path connected to conduct the entirety of the current returned to the flight  
15 tube such that the flight tube is maintained at a desired potential relative to the substrate holder, and a return current monitor arranged to provide a signal representative of the return current flowing through the return current path.

20

2. An ion implantation apparatus as claimed in claim 1, in which the power supply generates a potential difference between the substrate holder and flight tube such that the ions are decelerated between  
25 the flight tube and the substrate holder.

3. An ion implantation apparatus comprising a holder for a substrate to be implanted, a source of  
30 ions to be implanted in the substrate, a flight tube through which ions from the source travel towards the holder, an ion accelerator arranged to supply an acceleration bias between the source and the flight tube such that the ions are accelerated to an  
35 acceleration energy, a low resistance, electrically conductive return current path connected to conduct the entirety of the current returned to the flight

5 tube such that the flight tube is maintained at substantially the same potential as the substrate holder, and a return current monitor arranged to provide a signal representative of the return current flowing through the return current path.

10 4. An ion implantation apparatus as claimed in claim 1, 2 or 3 further comprising a beam stop arranged to absorb a portion of the ion beam not absorbed by the substrate or substrate holder, and to generate a beam stop current therefrom, the beam stop current being returned to the flight tube via the return current path.

15 5. An ion implantation apparatus as claimed in claim 4, further comprising a comparator arranged to provide a signal representative of the difference between the return current through the return current path and the beam stop current.

20 6. An ion implantation apparatus comprising a holder for a substrate to be implanted, a source of ions to be implanted in the substrate, a flight tube through which ions from the source travel towards the holder, an ion accelerator arranged to supply an acceleration bias between the source and the flight tube such that the ions are accelerated to an acceleration energy, a beam stop arranged to absorb a portion of the ion beam not absorbed by the substrate or substrate holder, and to generate a beam stop current therefrom, an electrically conductive controlled current path connected to conduct the entirety of the current to the flight tube such that a desired potential difference is maintained between the substrate holder and flight tube, and a comparator arranged to provide a signal representative of the

difference between the controlled current through the return current path and the beam stop current.

5        7.    An apparatus claimed in any one of the preceding claims, further comprising scanning means for scanning the ions relative to the substrate.

10       8.    An apparatus as claimed in claim 7, in which the scanning means is arranged to scan both the substrate and the beam stop with the ions.

15       9.    An apparatus claimed in claim 7 or claim 8, in which the scanning means scans the substrate relative to a fixed ion beam direction.

20       10.   An apparatus as claimed in any of the preceding claims, in which the substrate holder comprises a plurality of substrate supports each mounted relative to a rotatable hub.

25       11.   An apparatus as claimed in any of the preceding claims, in which the beam stop includes a Faraday-type detector.

30       12.   An apparatus as claimed in any one of the preceding claims, in which the flight tube includes mass selection means arranged to select only a proportion of the accelerated ions to be implanted into the substrate based upon the mass and charge of the said accelerated ions.

35       13.   A method of implanting ions in a substrate at a desired implant energy, comprising accelerating ions to a transport energy by supplying an acceleration bias between an ion source and a flight tube through which the ions travel, transporting the ions through the flight tube to the substrate,

generating a return current signal representative of the entirety of the current returned to the flight tube, the return current being controlled such that a desired potential difference is maintained between the substrate holder and flight tube, and monitoring the ions transported through the flight tube to the substrate based upon the signal representative of the return current.

10           14. A method as claimed in claim 13, further comprising absorbing in a beam stop a portion of the ion beam not absorbed by the substrate or substrate holder, and generating a beam stop current signal representative of that portion of the ion beam not  
15 absorbed by the substrate.

          15. A method as claimed in claim 14, further comprising comparing the beam stop current signal with the return current signal.

20           16. A method as claimed in claim 13, 14 or 15, further comprising scanning the ion beam relative to the substrate.

25           17. A method of monitoring the quality of an ion beam in an ion implantation apparatus, comprising accelerating ions to a transport energy by supplying an acceleration bias between an ion source and a flight tube through which the ions travel,  
30 transporting the ions as in an ion beam through the flight tube to a substrate, generating a return current signal representative of the entirety of the current returned to the flight tube, the return current being controlled such that a desired potential  
35 difference is maintained between the substrate holder and flight tube, and monitoring the quality of the ion beam based upon the signal representative of the



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return current.

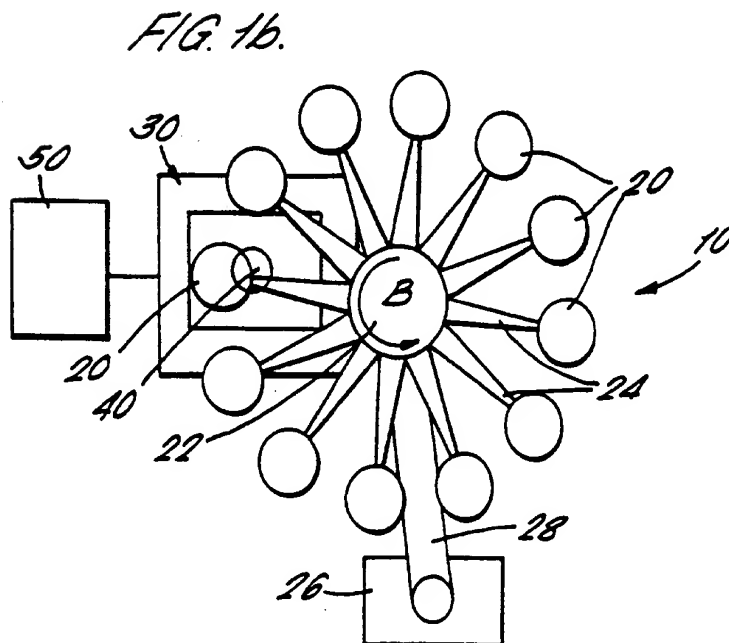
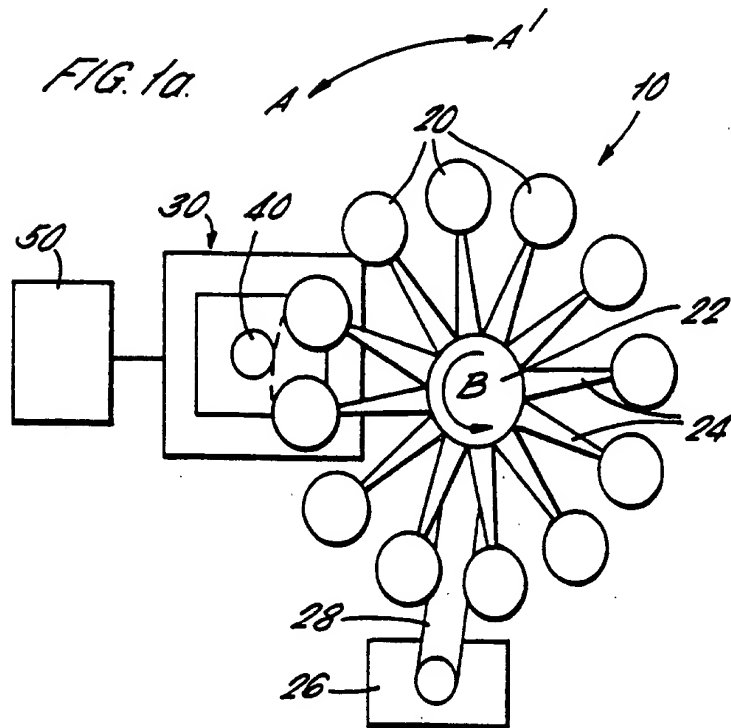
18. A method as claimed in claim 16, further  
comprising selecting only a proportion of the  
5 accelerated ions to be transported to the substrate  
based upon the mass and charge of the said accelerated  
ions.

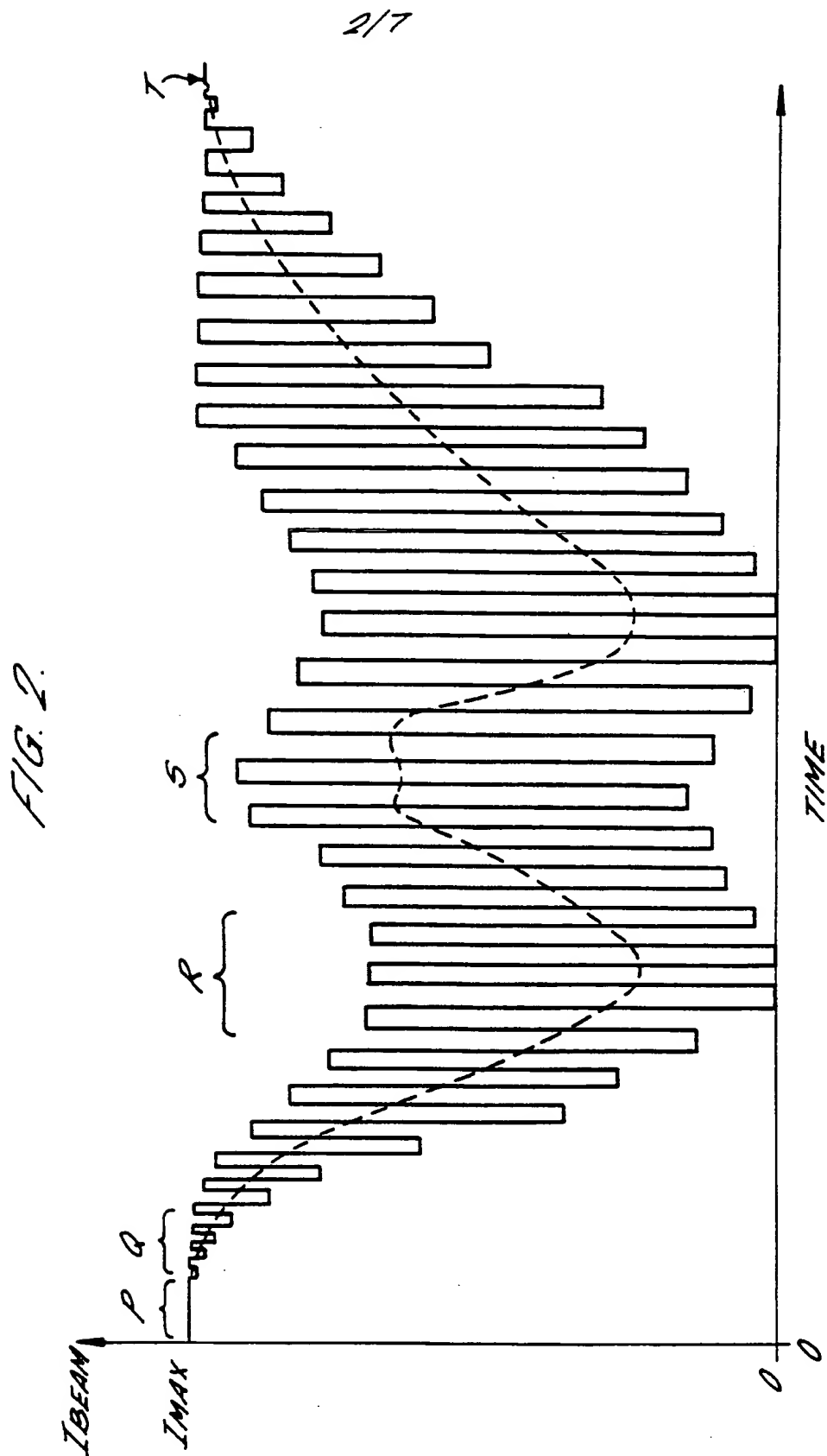
19. A method as claimed in claim 17, in which  
10 the quality of the ion beam is monitored only after  
the proportion of the accelerated ions to be  
transported has been selected.

20. An ion implantation apparatus substantially  
15 as herein described and with reference to Figures 3 to  
7.

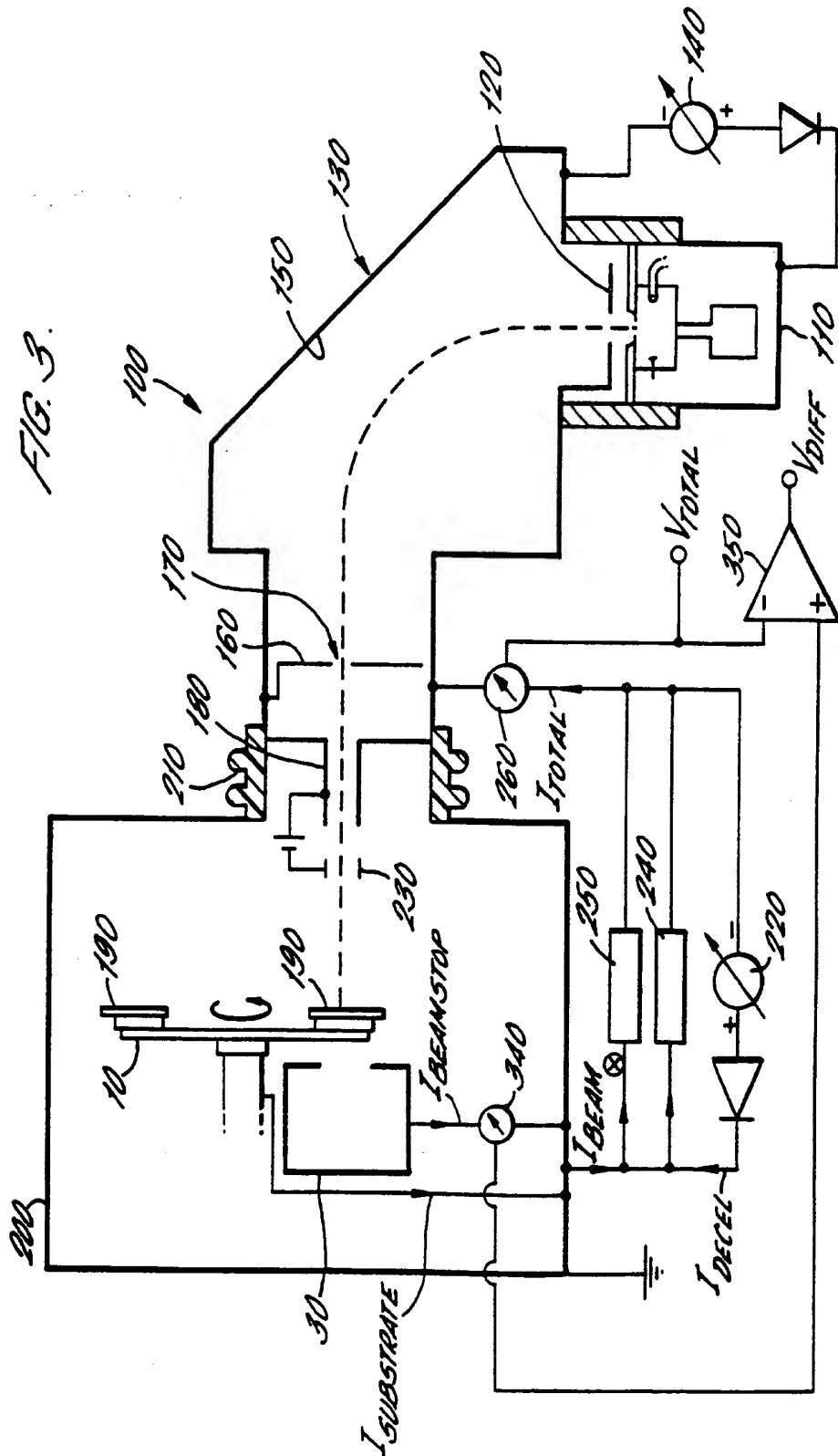
21. A method of implanting ions in a substrate  
substantially as herein described and with reference  
20 to Figures 3 to 7.

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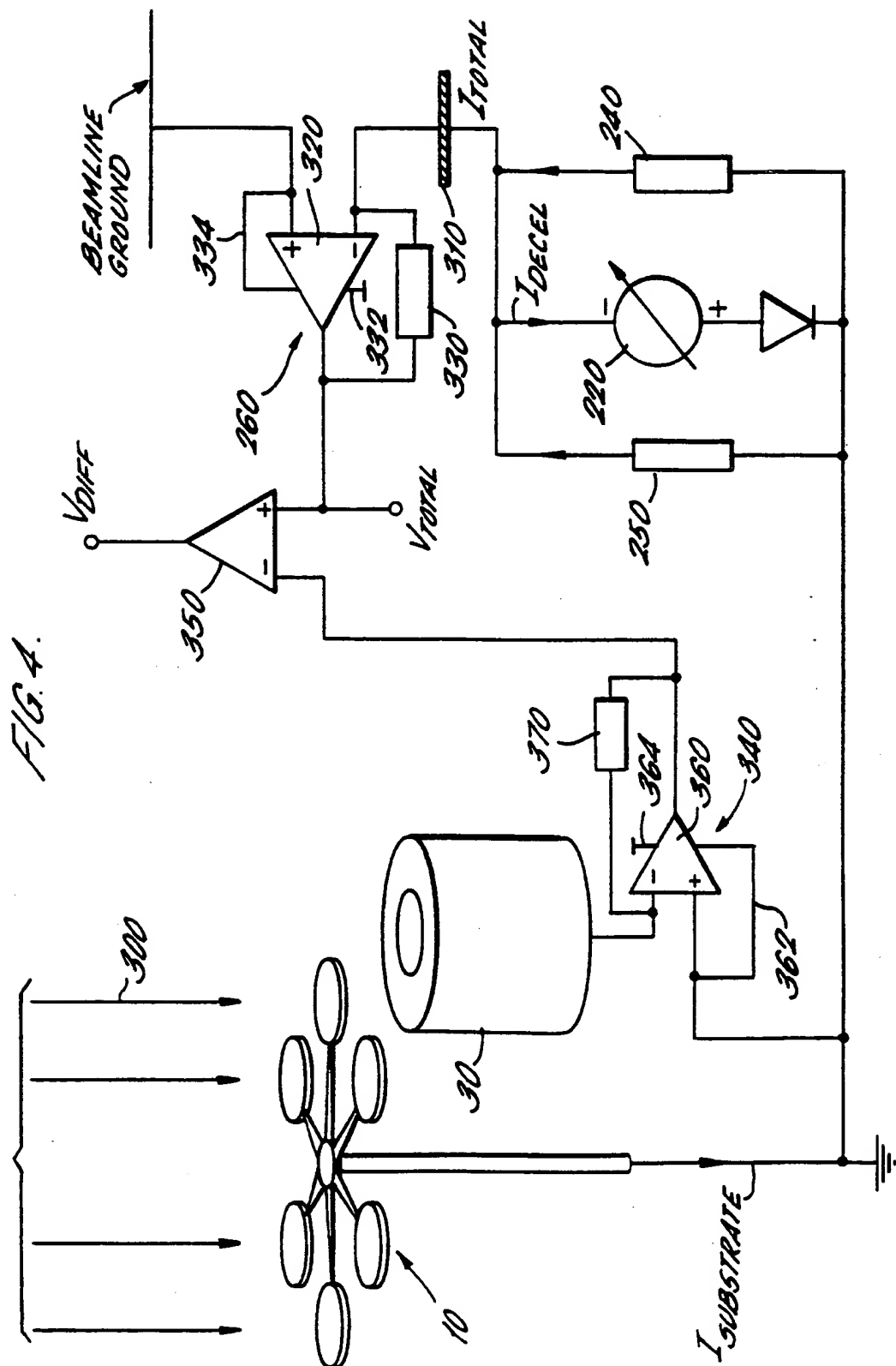




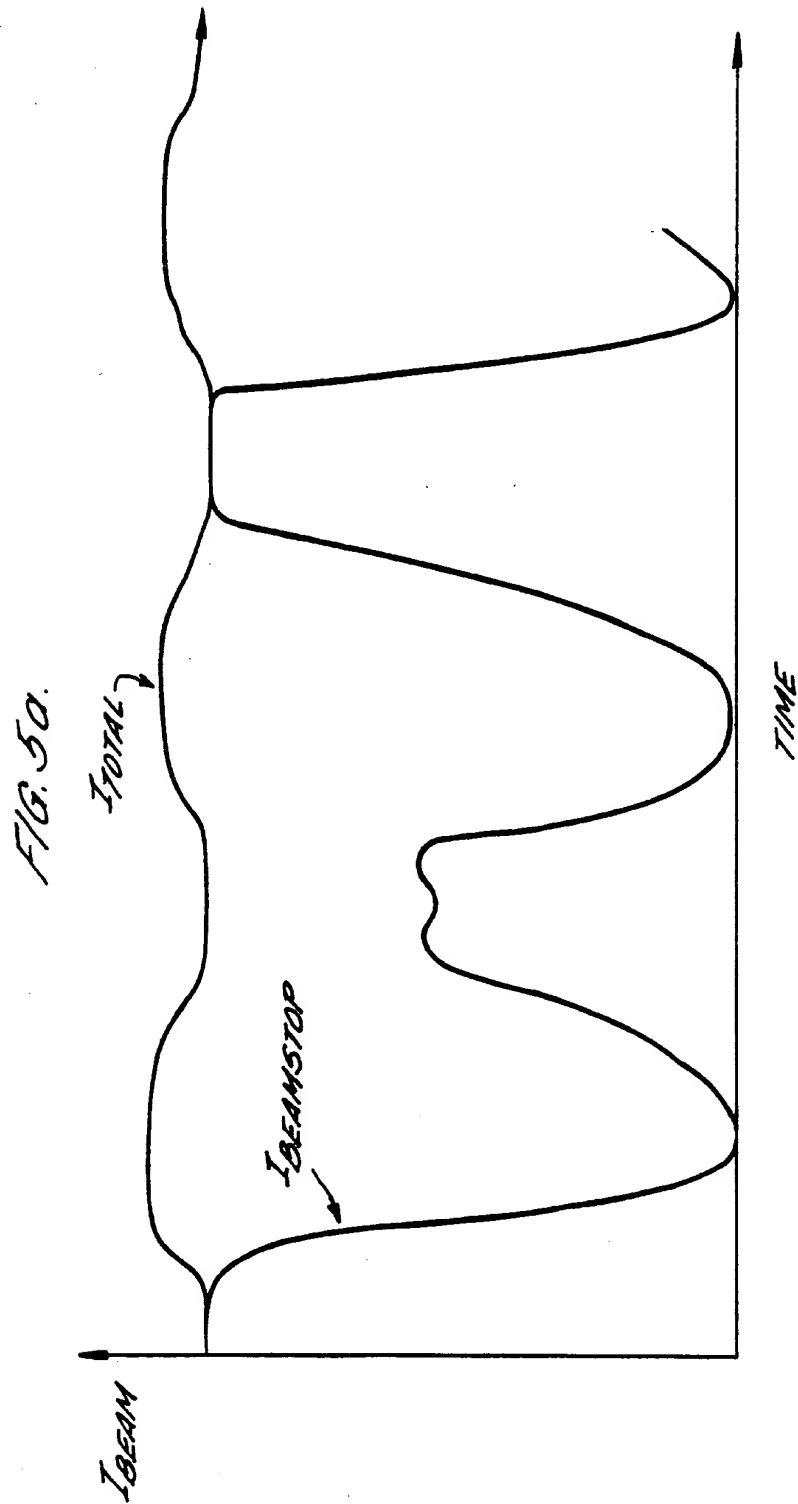
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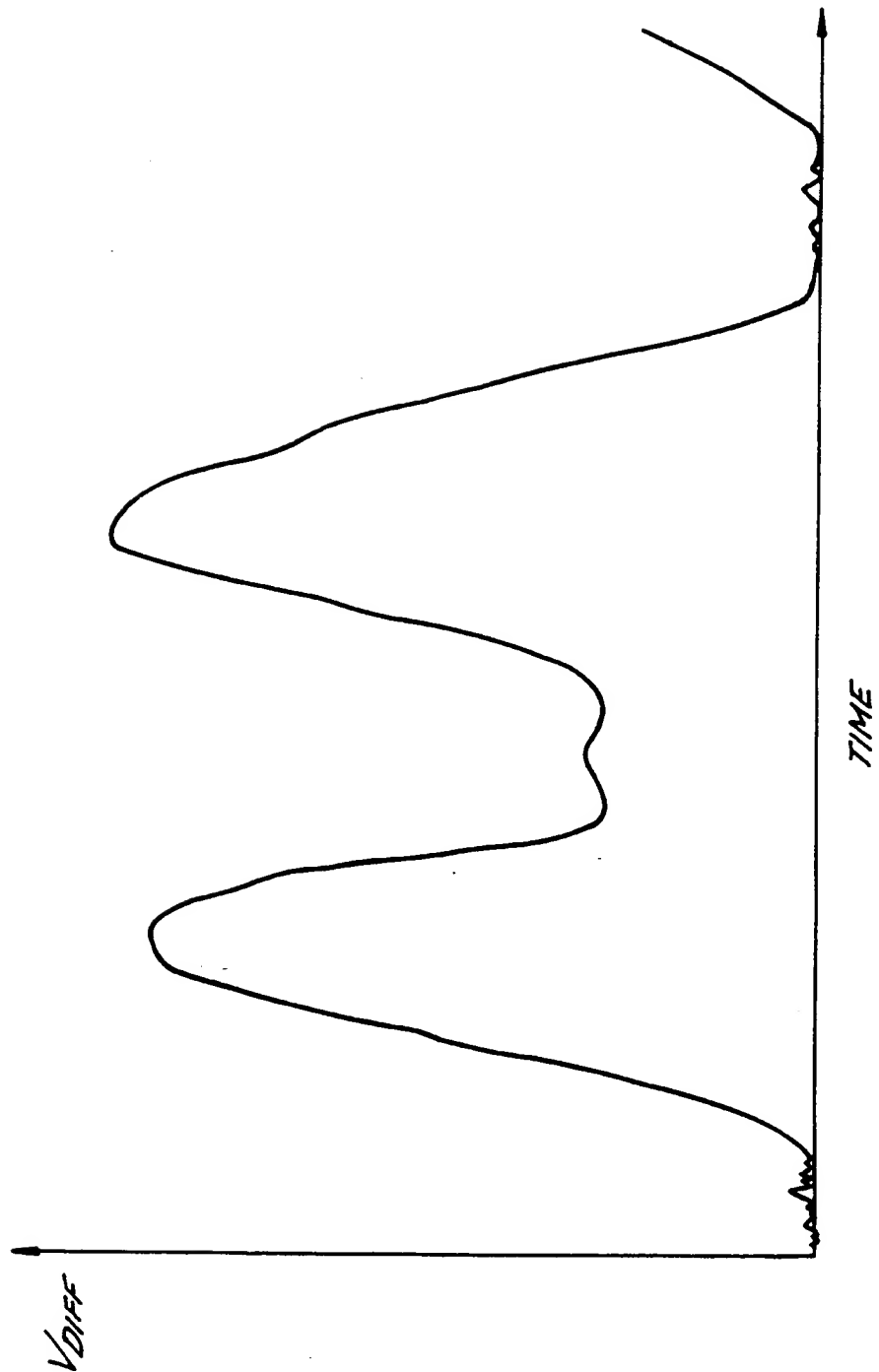


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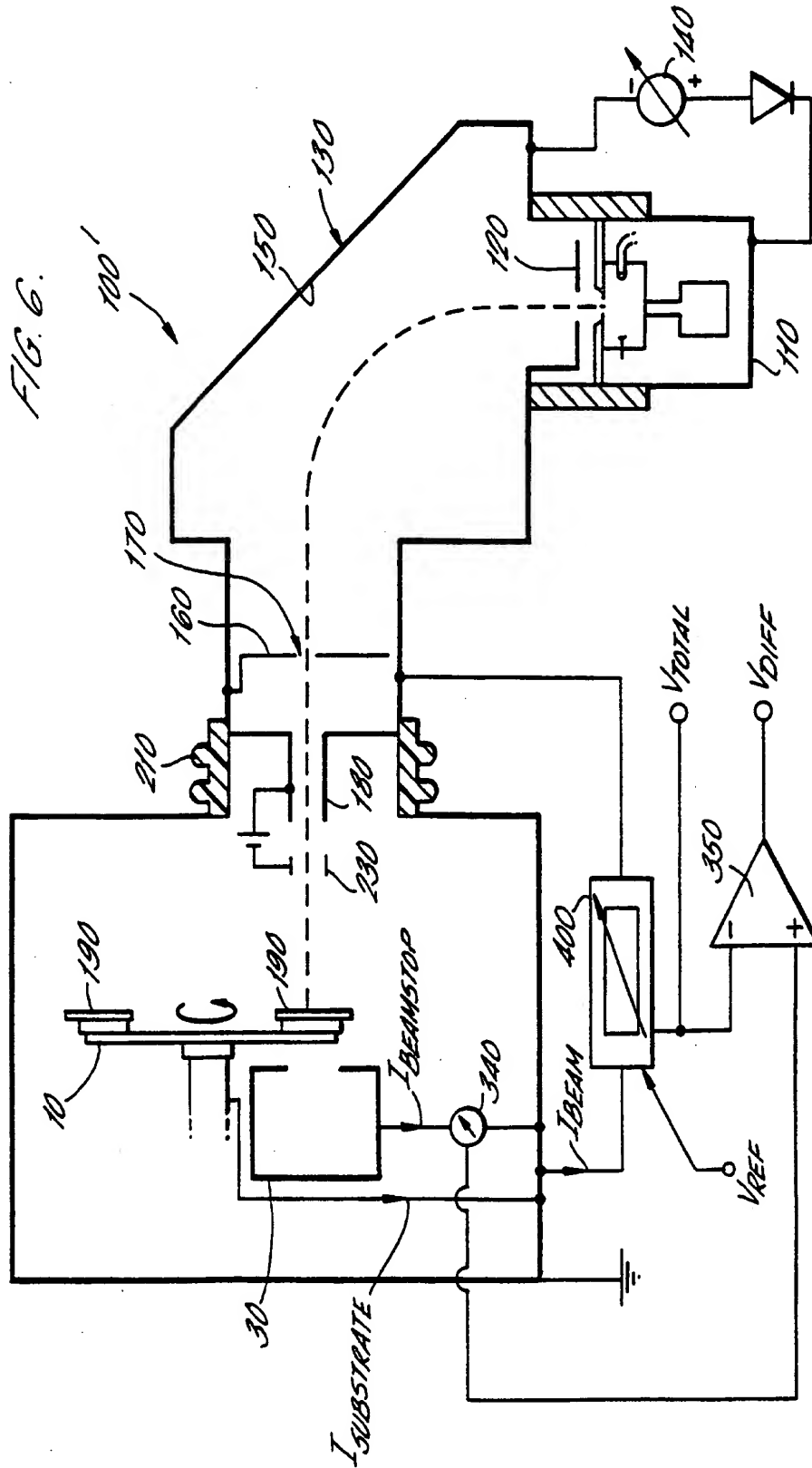


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FIG. 5b.



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## INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 99/02087

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 7 H01J37/317 H01J37/304

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	GB 2 307 592 A (APPLIED MATERIALS INC) 28 May 1997 (1997-05-28) page 9, line 32 -page 14, line 5; figures 2,3	1-3, 13, 17
Y	<p>---</p> <p>PATENT ABSTRACTS OF JAPAN vol. 1998, no. 10, 31 August 1998 (1998-08-31) &amp; JP 10 134760 A (HITACHI LTD), 22 May 1998 (1998-05-22) abstract</p> <p>---</p> <p>-/--</p>	1-3, 13, 17

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

13 October 1999

Date of mailing of the international search report

21/10/1999

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
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## INTERNATIONAL SEARCH REPORT

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## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	HARRISON B ET AL: "RESISTIVE DECELERATION IN THE XRLEAP IMPLANTER" ION IMPLANTATION TECHNOLOGY. PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON ION IMPLANTATION TECHNOLOGY, 1 January 1997 (1997-01-01), pages 319-322, XP002046103 page 320, left-hand column, paragraph 3 -page 321, left-hand column, paragraph 2; figures 3,4 -----	1-3, 13
A	US 5 641 969 A (COOKE RICHARD H ET AL) 24 June 1997 (1997-06-24) the whole document -----	7-12

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information on patent family members

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PCT/GB 99/02087

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JP 10134760 A	22-05-1998	NONE	
US 5641969 A	24-06-1997	NONE	

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